Formosa Plastics

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January 18, 2013

Via e-mail and Certified Mail:
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Ms. Nancy Fagan
Project Coordinator
6PD-O
U. S. Environmental Protection Agency
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

RE: Bench-Scale Treatability Testing Report
RCRA Docket No. VI-001(h)-90-H
3008(h) Administrative Order on Consent
EPA I. D. No. TXT490011293
Solid Waste Registration No. 31945

Dear Ms. Fagan:

Please find attached the Bench-Scale Treatability Testing Report. This report presents the results of the In-Situ Chemical Oxidation (ISCO) and Mass Removal tests. It does not include the results for the Enhanced Bioremediation test, as this test is only partially complete. FPC-TX will submit an addendum to this report once the results are final.

This document is being submitted as required by Amendment No. 2 to the 3008(h) Order, TASK XI: Corrective Measures Implementation Program.

If you have any questions about this report, please contact Matt Brogger at (361) 987- 7468 or by e-mail at mattb@ftpc.fpcusa.com.

Sincerely

R. P. Smith
Vice President/General Manager
Formosa Plastics Corporation, Texas

Attachment

cc: Ms. Maureen Hatfield, (MC-127)
TCEQ
P.O. Box 13087
Austin, TX 78711-3087

Certified Mail: 7011 0110 0000 1783 3203

REDOX map
DO → nitrate → Mn → iron → sulfate → finally CO2 (methanogenic)

competing e' acceptors
- DO
- bioavailable iron
- sulfate

may limit effectiveness of substrate addition

FMC

ENVIRONMENTAL SOLUTIONS

MEMO

To: Matthew Wickham

From: Eva Janzen

Date: January 9, 2013

Copies: Josephine Molin

~~SO4 concentration <500 ppm is most suitable to~~ reductive dechlorination

→ bio ORP

SUBJECT: FA11-233 – Paster, Behling & Wheeler LLC – Progress Report #2

organic → abiotic
→ inorganic

(band + ZVI [e' donor] causes dechlorination reaction

The purpose of this memo is to present the results from the day 56 batch test sampling event. A detailed description of the batch test was provided in the first progress report (December 17, 2012).

RESULTS → DO?

VOC, pH and ORP data from the day 0 and 56 sampling events are summarized in Table 1. After eight weeks of treatment the EHC microcosm showed an 18% reduction in total VOCs when compared to the ambient control. Strong reducing conditions (-506 mV) were created in the EHC microcosm and a slight drop in pH was observed.

initial chem charac.

8 week results

Table 1: VOC concentrations, pH and ORP readings in the Site groundwater

Parameter Name	Day 0	Day 56 (8)			Unit
	Time Zero Jar (Ambient Control)	Ground Water Control Jar 2	Ambient Control Jar 2	EHC Jar 2	
1,1,2-Trichloroethane	7,800	7,900	7,300	4,700	ug/L
1,1-Dichloroethane	6,700	7,400	6,600	4,800	ug/L
1,1-Dichloroethene	1,300	1,400	1,400	ND (1,000)	ug/L
Benzene	2,400	2,400	2,200	1,600	ug/L
Chloroform	83,000	89,000	82,000	34,000	ug/L
cis-1,2-Dichloroethene	2,300	2,500	2,200	1,600	ug/L
Ethylbenzene	ND (25)	ND (500)	ND (500)	ND (500)	ug/L
Dichloromethane – Methylene Chloride	1,200	ND (5,000)	ND (5,000)	6,300	ug/L
Tetrachloroethene	1,900	1,300	1,300	730 J	ug/L
trans-1,2-Dichloroethene	3,400	3,400	3,000	1,700	ug/L
Trichloroethene	4,100	3,700	3,400	2,100	ug/L
Vinyl chloride	9,500	11,000	10,000	4,500	ug/L
1,2-Dichloroethane	1,500,000	1,400,000	1,300,000	1,100,000	ug/L
Total VOCs	**1,623,600**	**1,530,000**	**1,419,400**	**1,162,030**	**ug/L**

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ethane
methane
chloroethane

Parameter Name	Day 0	Day 56			Units
	Time Zero Jar (Ambient Control)	Water Control Jar 2	Ambient Control Jar 2	EHC Jar 2	
pH	6.04	6.00	6.04	5.88	SI units
ORP	310	436	423	-506	mV

DO

A comparison of the VOC data in the EHC microcosms on days 28 and 56 shows that with additional time, a greater reduction in a number of VOCs (1,1,2-TCA, 1,1-DCA, CF, cis-1,2-DCE, trans-1,2-DCE, TCE and VC) was supported (**Table 2**). The 1,2-DCA concentrations in the control and EHC microcosms were greater on day 56 than on day 28. This may be related to variability associated with setting up sacrificial jars.

different dilution

Table 2: VOC concentrations in the batch jars on days 28 and 56

8 wk

Parameter Name	Water Control		Ambient Control		EHC		Unit
	Day 28	Day 56	Day 28	Day 56	Day 28	Day 56	
1,1,2-Trichloroethane	9,600	7,900	8,700	7,300	7,800	4,700	ug/L
1,1-Dichloroethane	8,800	7,400	9,500	6,600	8,200	4,800	ug/L
1,1-Dichloroethene	ND (5,000)	1,400	ND (5,000)	1,400	ND (2,500)	ND (1,000)	ug/L
Benzene	2,900	2,400	2,800	2,200	2,400	1,600	ug/L
Chloroform	92,000	89,000	99,000	82,000	66,000	34,000	ug/L
cis-1,2-Dichloroethene	3300 J	2,500	3,400 J	2,200	2,500	1,600	ug/L
Ethylbenzene	ND (2,500)	ND (500)	ND (2,500)	ND (500)	ND (1,300)	ND (500)	ug/L
Methylene Chloride	ND (25,000)	ND (5,000)	ND (25,000)	ND (5,000)	ND (13,000)	6,300	ug/L
Tetrachloroethene	ND (5,000)	1,300	ND (5,000)	1,300	ND (2,500)	730	ug/L
trans-1,2-Dichloroethene	4000 J	3,400	4,200 J	3,000	3,400	1,700	ug/L
Trichloroethene	2,900	3,700	2,500	3,400	2,600	2,100	ug/L
Vinyl chloride	12,000	11,000	13,000	10,000	7,400	4,500	ug/L
1,2-Dichloroethane	1,200,000	1,400,000	1,100,000	1,300,000	990,000	1,100,000	ug/L
Total VOCs	**1,335,500**	**1,530,000**	**1,243,100**	**1,419,400**	**1,090,300**	**1,162,030**	**ug/L**

Continuing Work

The remaining microcosms are being incubated at room temperature and in the dark. The next sampling event is scheduled for January 14, 2013 (12 weeks). Based on the results of the day 56 sampling event, FMC recommends bioaugmenting the remaining EHC microcosms with a commercially available culture. Given the mixture of chlorinated ethenes and ethanes in the site groundwater, our recommendation would be to use a mixed culture of SDC-9 (*Dehalococcoides*) and TCA-20 (*Dehalobacter*). bioaug 1/15

Sampled 3RD set

2 on 1/29 sample

- data reported week of 2/11

BENCH-SCALE TREATABILITY TESTING REPORT
FORMOSA PLASTICS CORPORATION, TEXAS
POINT COMFORT, TEXAS

PASTOR, BEHLING & WHEELER, LLC
consulting engineers and scientists

BENCH-SCALE TREATABILITY TESTING REPORT
FORMOSA PLASTICS CORPORATION, TEXAS
POINT COMFORT, TEXAS

Prepared for:

FORMOSA PLASTICS CORPORATION
Point Comfort, Texas

January 15, 2013

Prepared by:

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PBW Project No. 3251

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

AOC	Area of Concern
ASP	Activated Sodium Persulfate
CAO	Corrective Action Objective
COPC	Chemical of Potential Concern
CSM	Conceptual Site Model
DNAPL	Dense Non-Aqueous Phase Liquid
DPE	Dual-Phase Extraction
EDC	1,2-Dichloroethane (or Ethylene Dichloride)
EPA	U.S. Environmental Protection Agency
FMC	FMC Environmental Solutions
FPC-TX	Formosa Plastics Corporation, Texas
GPM	Gallons Per Minute
ISCO	In-situ Chemical Oxidation
ISOTEC	In-Situ Oxidative Technologies, Inc.
mg/L	Milligrams Per Liter
MPE	Multi-Phase Extraction
ORP	Oxidation-Reduction Potential
PBW	Pastor, Behling & Wheeler, LLC
PCL	Protective Concentration Level
RFI	RCRA Facility Investigation
RMP	Risk Management Plan
ROI	Radius of Influence
SWMU	Solid Waste Management Unit
SVE	Soil Vapor Extraction
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TRRP	Texas Risk Reduction Program
VCM	Vinyl Chloride Monomer Process Area
VOCs	Volatile Organic Compounds
WWTP	Former Waste Water Treatment Plant
ZVI	Zero-Valent Iron

1.0 INTRODUCTION

In accordance with the U.S. Environmental Protection Agency (EPA) Administrative Order on Consent with Corrective Action Plan (CAP) dated February 27, 1991 (EPA Docket No. VI-001(h)-90-H; EPA I.D. No. TXT490011293), as amended, Formosa Plastics Corporation, Texas (FPC-TX) has undertaken measures to characterize and remediate soil and groundwater affected by volatile organic compounds (VOCs) at the Point Comfort facility. The FPC-TX facility is located in Calhoun County along State Highway 35 and Farm to Market Road (FM) 1593, adjacent to Lavaca Bay (Figure 1). The EPA's 1991 Order addresses a facility of approximately 256 acres.

As documented in the Final Risk Management Plan (RMP) (Tetra Tech, 2010), remaining Solid Waste Management Units (SWMUs) and associated potentially impacted soil and groundwater have been segregated into two distinct Areas of Concern (AOC) at the FPC-TX facility: AOC 1 – the former Waste Water Treatment Plant (WWTP) area located in the eastern portion of the site; and AOC 2 – the Vinyl Chloride Monomer (VCM) Process area located in the central portion of the facility.

In July 2012, FPC-TX submitted a work plan (PBW, 2012a) for conducting a bench-scale treatability study of soil and groundwater from the VCM and former WWTP areas. The work plan was approved by EPA in August 2012. The work plan proposed the evaluation of the following technologies:

1) In-situ chemical oxidation (ISCO); – treatment
2) In-situ biological treatment; and – treatment
3) Dual-phase extraction and removal (Mass Removal). – removal

This report provides the results and conclusions of the treatability study performed per the approved work plan.

☆ Add ⇒ CAO 1 – overall objective is to contain the plume

CAO 2 – FPC <u>must</u> remove or treat <u>source materials</u>

2.0 BACKGROUND

Soil and groundwater affected by volatile organic compounds (VOCs) are present at Formosa's Point Comfort facility. A comprehensive summary of existing environmental data was provided in the Areas of Concern Characterization Work Plan (Tetra Tech, 2012) and is not reproduced here. The Final Risk Management Plan (RMP) (Tetra Tech, 2010) also includes a detailed discussion of the nature and extent of potential soil and groundwater impacts and a conceptual site model (CSM). Both of the summaries mentioned above describe the results of the RCRA Facility Investigation (RFI) (C-K Associates, Inc., 1995). Further investigation of site soil and groundwater in the VCM and former WWTP areas was performed recently per the AOC Characterization Work Plan (Tetra Tech, 2012), as documented in the AOC Characterization Report (PBW, 2012b).

The main constituent of potential concern (COPC) identified in site soil and groundwater is 1,2-Dichloroethane (EDC). Other chlorinated hydrocarbons are also present in soil and groundwater samples at lower concentrations (e.g., chloroform, 1,1,2-trichloroethane, cis-1,2-dichoroethane, trans-1,2-dichloroethane, trichloroethene, vinyl chloride). There are two main areas at the site with COPCs at elevated concentrations: the former Waste Water Treatment Plant (WWTP) area in the eastern portion of the site and the VCM Process area in the central portion of the site. These areas are shown on Figure 2 as Areas of Concern (AOC) 1 and 2, respectively.

In the RMP, the Texas Risk Reduction Program (TRRP) protective concentration levels (PCLs) were used as a screening tool and compared to existing soil data. The $^{GW}Soil_{Ing}$ PCL (representing the soil-to-groundwater leaching and potential groundwater ingestion pathway) and the $^{Tot}Soil_{Comb}$ PCL (representing the inhalation, ingestion and dermal contact soil pathways) were identified as the most appropriate screening values. The $^{Tot}Soil_{Comb}$ PCL is generally several orders-of-magnitude higher than the $^{GW}Soil_{Ing}$ PCL for the COPCs at the site. As discussed in the RMP, contaminant concentrations in excess of the $^{Tot}Soil_{Comb}$ PCL were identified in soil samples collected at six SWMUs. Therefore, these areas represent the primary impacted soil areas at the site:

- SWMU #1 – Storm Water Basin;
- SWMU #21/22/23 – Inactive units adjacent to the active incineration area;
- SWMU #3 – Surge Basin; and
- SWMU #4 – Emergency Basin.

Evaluation of the existing soil data for the site also included an analysis of whether the soil samples collected during the RFI were from unsaturated soil or saturated soil. The saturation of the soil is an important factor in the consideration of remedial alternatives for soil since saturated soil is best remediated via groundwater remediation technologies. The analysis of the soil data indicated that the soil samples from the interior of the Surge Basin and Emergency Basin are representative of unsaturated soil conditions. Coupled with the relatively high concentrations of EDC in the samples from these basins, these locations were considered ideal for collection of soil samples for treatability testing.

In the RMP, groundwater concentration data were evaluated for both elevated concentrations and trends. In the context of this work plan, the trend evaluation is less important than the elevated concentrations, since the treatability tests will be performed on groundwater that currently exhibits elevated COPC concentrations. In the RMP, wells where EDC concentrations in groundwater samples exceed or have exceeded one percent (1%) of the aqueous solubility for EDC (87 mg/L) were identified, as follows:

- P-56 - AOC 1 – WWTP Area, Zone A
- P-57 - AOC 1 – WWTP Area, Zone A
- P-3 - AOC 2 – VCM Area, Zone A
- P-36 - AOC 2 – VCM Area, Zone A
- D-11 - AOC 2 – VCM Area, Zone C
- D-41 - AOC 2 – VCM Area, Zone C
- RD-1 - AOC 2 – VCM Area, Zone C
- RS-1 - AOC 2 – VCM Area, Zone A/B
- RS-6 - AOC 1 – WWTP Area, Zone A
- P-12 - AOC 2 – VCM Area, Zone B
- D-2 - AOC 2 – VCM Area, Zone C
- RS-3 - AOC 2 – VCM Area, Zone A
- RD-3 - AOC 2 – VCM Area, Zone B

used to define "sources"
must remove or TREAT

Although EDC concentrations, and occasionally chloroform concentrations, exceed 1% of the aqueous solubility limit in some samples, dense non-aqueous phase liquid (DNAPL) has not been observed in monitoring wells at the site. Due to

Based on the available information summarized above, the Surge Basin and Emergency Basin areas appeared to be the best locations for treatability studies since these areas appear to have the highest COPC concentrations. Furthermore, these locations are in an easily accessible, inactive portion of the facility. Specific locations for testing are described in Section 4.0.

3.0 TREATABILITY STUDY DESIGN

3.1 Introduction

Based on the specific characteristics of the site (e.g., groundwater quality, concentrations of COPCs in soil and groundwater, subsurface conditions, logistical issues, etc.), three remediation technologies were implemented for treatability testing: 1) in-situ chemical oxidation (ISCO), 2) enhanced bioremediation, and 3) multi-phase extraction (MPE). These three technologies have the potential to help meet the corrective action objectives (CAOs) and remediation goals for the site.

Depending on the technology, treatability testing can be performed in the laboratory (i.e., bench-scale testing) or in the field (pilot-scale testing). Typically, bench-scale testing is performed first (if feasible). If the bench-scale test results are positive and indicate that a particular technology may be effective at a given site, pilot-scale testing may be warranted. Bench-scale testing was chosen to initially evaluate the ISCO and enhanced bioremediation technologies. Multi-phase extraction is not typically performed at the bench-scale level and should be performed as a pilot-scale test at the site where the COCs are present in environmental media. Therefore, the multi-phase extraction test was performed as a pilot-scale test at the FPC-TX site. Multi-phase extraction is also referred to as dual-phase extraction (DPE) in this report.

The following sections describe the treatability testing program designed to evaluate the selected remediation technologies.

3.2 In-Situ Chemical Oxidation (ISCO)

In-situ chemical oxidation (ISCO) uses strong oxidants to reduce the concentrations of targeted contaminants to acceptable levels. ISCO is accomplished by injecting or otherwise introducing the oxidants directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. Chlorinated ethanes such as EDC are amenable to destruction by chemical oxidation and ISCO is potentially an effective treatment method for soil and groundwater impacted by EDC at the site.

This technology is mainly applicable for saturated media including soil and groundwater; however, in some cases ISCO can be configured to address unsaturated soil by artificially saturating the vadose zone to permit treatment.

Based on the review of potential available oxidant chemistries and the properties of site COPCs, two oxidants (reagents) were selected for bench-scale testing: (1) modified Fenton's reagent (MFR), and (2) activated sodium persulfate (ASP). The sodium persulfate was evaluated using two activation methods, (1) heat (ASP-HEAT) and (2) alkali (ASP-ALK). A bench-scale test was performed for each oxidant.

Specific goals of the bench-scale study were to:

- Determine destruction of COPCs for each oxidant;
- Determine whether removal by modified Fenton's reagent is due to destruction or volatilization;
- Evaluate the effect of treatment on secondary water quality parameters;
- Measure soil oxidant demand for activated persulfate (each activator); and
- Estimate the longevity of modified Fenton's reagent in the presence of soil.

Groundwater and soil samples for the ISCO bench scale study were collected from the WWTP Surge Basin/Emergency Basin area. An evaluation of historic groundwater data indicated that samples from wells P-56 and P-57 (Figure 4) typically exhibit elevated concentrations of EDC and were considered suitable for the treatability testing[1]. Soil samples were collected using direct-push technology from borings immediately adjacent to wells P-56 and P-57. The soil samples were collected from the Zone A sand interval from approximately 11.9 to 13.6 feet below ground level (see boring log for well TS-1 in Appendix A). Four separate borings were necessary to collect the volume of material needed for the ISCO bench-scale treatability study (as well the material needed for the bench-scale bioremediation study, see Section 4.3). The borings were drilled as near as feasible to one another. All borings were properly plugged and abandoned immediately after the completion of sampling. The soil samples were collected using standard collection and decontamination techniques that minimized cross-contamination, were immediately placed on ice for preservation, and were shipped to ISOTEC using standard chain-of-custody procedures. Groundwater samples were collected from well P-56 using the same methods used during the quarterly groundwater monitoring events.

In-Situ Oxidative Technologies, Inc. (ISOTEC) of Lawrenceville, New Jersey performed the ISCO bench-scale studies on the site soil and groundwater, as described in their study proposal included in the work plan. ISOTEC's study report is included in Appendix B of this report. The results of the study are described in Section 5.1.

[1] The concentrations of EDC in the samples from P-56 and P-57 were 1,299.7 mg/L and 667.1 mg/L, respectively, in the first quarter 2012 sampling event.

3.3 Enhanced Bioremediation

Enhanced bioremediation is a general term used to describe a variety of remedial technologies whereby the natural microbes in the environment are supplemented with additional microbes (bioaugmentation), nutrients, oxygen (aerobic bioremediation) and/or reducing agents (anaerobic bioremediation) to enhance the natural destruction of contaminants. Anaerobic bioremediation (also called reductive dechlorination or bio-chemical reduction) is considered a potential remedial technology for the FPC-TX site since chlorinated hydrocarbons such as EDC are amenable to reductive dechlorination and also for the following reasons:

1) The presence of high ethene concentrations from samples of groundwater from wells P-56 and P-57 may be indicative of the presence of anaerobic microorganisms that have adapted to site conditions and are potentially capable of degrading EDC;
2) The site groundwater exhibits overall reducing conditions (negative ORP values) and near neutral pH which indicates that conditions may be suitable for reductive dechlorination.

As for ISCO, this technology is mainly applicable for saturated media including soil and groundwater; however, in some cases bioremediation can be configured to address unsaturated soil by artificially saturating the vadose zone to permit treatment.

To evaluate the potential for reductive dechlorination to serve as a remedial technology at the site, a bench-scale treatability study was developed that used FMC Environmental Solutions (FMC) EHC® technology. The EHC technology uses a reagent that includes a controlled-release, integrated carbon (as a nutrient source) and zero-valent iron (ZVI) as a reducing agent to stimulate the reductive dechlorination of chlorinated solvents such as EDC.

As for the ISCO bench-scale study, groundwater and soil samples for the bioremediation bench scale study were collected from the WWTP Surge Basin/Emergency Basin area (see Section 4.2). The samples were collected at the same time as the samples for the ISCO treatability study.

FMC is currently performing a bench-scale treatability study to evaluate the bioremediation technology. The results of the study will be reported via an addendum to this report.

3.4 Mass Removal Pilot Testing

Dual-phase extraction (DPE) (also called dual-phase recovery) is a proven contaminant mass removal technology for highly-contaminated source areas such as those identified at the site. Dual-phase extraction removes contaminants from both groundwater and vadose soils. Extraction from the vadose zone alone is called soil vapor extraction (SVE). Dual-phase extraction can be successful in a low permeable, low yield, heterogeneous formation such as that at the FPC-TX site and can achieve high contaminant mass removal rates. A dual-phase extraction system at the FPC-TX site could potentially remove a substantial portion of the contaminant mass in a relatively short period of time, thus reducing the overall remediation cost.

Gainco Inc. (Gainco) performed mass removal testing by removing soil vapor and groundwater from the subsurface by means of a vacuum. The test was performed at the well cluster including P-56, P-57 and RS-6. Well RS-6 was not used because the well casing contains a semi-permanent groundwater extraction pump and piping. Because the wells in this well cluster are relatively close together (less than 20 feet from one another), an additional temporary well was installed to evaluate the radius of influence of the vacuum. The well (TS-2) was installed using a geoprobe and was constructed to a depth of 15 feet below ground surface (bgs) with five feet of screen. For the DPE testing, Gainco provided mobile equipment powered by a self-contained power source and the appropriately sized high vacuum extraction equipment (e.g., liquid ring pump) capable of removing vapor and groundwater from the wells. The pilot test was conducted over two days, with the SVE and baseline groundwater extraction data collected the first day and high vacuum DPE data collected the second day.

Gainco's study report is included in Appendix C. The results of the study are described in Section 5.3.

4.0 STUDY RESULTS

4.1 ISCO

ISOTEC performed the ISCO study on site soil and groundwater samples as described in their report contained in Appendix B. Per the work plan (PBW, 2012a), ISOTEC used site soil and groundwater to set up a series of test reactors to perform the study. Site soil and groundwater samples were first composited (from the separate containers sent to ISOTEC by PBW). A portion of the composited soil and groundwater was submitted to a laboratory for initial chemical characterization (see Table 1 of this report and Table 1 of Appendix B). The remaining composited soil and groundwater were prepared into a slurry by mixing at a soil-to-water ratio of 2:1 by weight[2]. A total of three tests were performed, one for each of the three reagents (MFR, heat-activated sodium persulfate (ASP-HEAT), and alkali-activated sodium persulfate (ASP-ALK)). All three tests were performed with an oxidant and an activating agent, as shown in the following table.

TEST	OXIDANT	ACTIVATING AGENT
Modified Fenton's Reagent (MFR)	Stabilized hydrogen peroxide (H_2O_2)	ISOTEC Catalyst Series 4260 (circum-neutral pH organometallic complex (chelated iron)
Activated Sodium Persulfate – Alkali (ASP-ALK)	Sodium persulfate ($Na_2S_2O_8$)	Sodium hydroxide (NaOH)
Activated Sodium Persulfate – Heat (ASP-HEAT)	Sodium persulfate ($Na_2S_2O_8$)	Heat (60°C)

For each test, a total of four reactors were set up, with one reactor serving as the "control' and the remaining three serving as "treatment" reactors. The reactors consisted of 250 mL glass jars with screw-top caps fitted with Teflon septa to facilitate reagent injection. Each reactor consisted of the same quantity of soil/groundwater slurry at the start of the tests. Reagents were evaluated at three doses, as shown in the following table.

OXIDANT DOSE	MFR TEST	ASP-ALK TEST	ASP-HEAT TEST
Low Dose	6.6 g/Kg	6 g/Kg	6 g/Kg
Medium Dose	33.3 g/Kg	30 g/Kg	30 g/Kg
High Dose	66 g/Kg	60 g/Kg	60 g/Kg
Test Duration	3 days	10 days	1 day

[2] A 2:1 mixture by weight consisted of 100 grams of soil and 50 ml of water. Water has a density of 1 g/mL.

The duration of the tests ranged from 1 day to 10 days, as shown in the table. At the end of the test, the reactors were "quenched" to terminate the reactions to minimize subsequent VOC loss. The contents of each reactor was then separated into solid and aqueous phases and submitted for the chemical analyses described in the work plan. A summary of the post-test chemical analyses is provided on Table 1 of this report.

The results of post-test chemical analyses of the soil and groundwater indicate that all three reagents were effective at treating EDC and other VOCs detected at the site (Table 1). The maximum EDC and total VOC reduction was greater than 99% in both the solid and aqueous phases. Destruction of EDC was also greater at the higher reagent doses, as would be expected. In general, the medium reagent dose for all three reagents resulted in a minimum 86% reduction in EDC/VOC concentrations. The high reagent dose for all three reagents resulted in a minimum 98% reduction in EDC/VOC concentrations. Among the three reagents, MFR resulted in the greatest EDC/VOC concentration reductions at the low dose. ASP-ALK resulted in the greatest EDC/VOC concentration reductions at the high dose (99.9%).

ISOTEC noted that characteristics of the site also influence the ability of the reagents to reduce EDC/VOC concentrations in soil and groundwater. Iron and manganese concentrations in soil and groundwater are important catalysts in the MFR and persulfate reactions that result in EDC/VOC destruction. The total iron, ferrous iron and manganese concentrations in site groundwater are below the minimum concentrations necessary for proper activation of the reagents. Therefore, external catalyst would be required for field application of these reagents. Furthermore, although iron and manganese are found in site soil, they are mostly in the form of oxyhydroxides. The oxyhydroxides will promote some Fenton-like reactions, but they are generally unavailable to act as effective catalysts and can result in oxidant wastage (i.e., the oxidant is used in chemical reactions other than those responsible for EDC/VOC reduction). Finally, the background total organic carbon (TOC) concentrations in site soil and groundwater are expected to exert a moderate to high oxidant demand (oxidant scavenging). In other words, the TOC will compete with the contaminants for oxidant and result in lower VOC reductions than in a system with less available TOC.

The effects of the reagents on the general chemistry of the treated groundwater were also evaluated during the study (see Table 2 of this report), as follows:

1) pH – The pH of site groundwater is typically in the range of 6-7 standard pH units. The pH of the groundwater from well P-56 was 6.55 at the time of sample collection. The pH of the treated water remained in this general range for the MFR and ASP-HEAT tests. A slight rise in pH was observed in the MFR test; a slight decrease was observed in the ASP-HEAT test. The pH of the

groundwater in the ASP-ALK test increased significantly due to addition of the highly-alkaline sodium hydroxide.

2) ORP – the ORP of site groundwater is variable, ranging from slightly positive to slightly negative. The ORP of the groundwater from well P-56 was measured at -125 at the time of sample collection. The ORP of the treated groundwater remained stable for the MFR test. The ORP of the treated groundwater decreased during the ASP-ALK test. The ORP increased slightly during the ASP-HEAT test. It is important to note that ORP is a sensitive parameter and is difficult to measure, which may explain the variability observed in the test results.
3) TDS – the TDS of site groundwater is variable, ranging from less than 5,000 mg/L to greater than 10,000 mg/L. The TDS of the groundwater from well P-56 was 9,150 mg/L. The TDS of the treated groundwater increased slightly in the MFR test. The TDS of the treated groundwater increased significantly during the persulfate tests due to the addition of the sulfate present in the reagent.

As noted on page 13 of the ISOTEC report, a bench-scale study only evaluates the oxidation "chemistry" of the various oxidants as it relates to site contaminants and certain site characteristics. In other words, it evaluates whether the oxidants can treat the contaminants present at the site. In the current study performed by ISOTEC, the oxidants were successful in reducing EDC and other VOC concentrations using site soil and groundwater.

Bench-scale conditions are very different from in-situ conditions. For instance, although the 2:1 soil-to-groundwater mixture is an industry standard for bench-scale tests, it does not simulate natural conditions. Natural in-situ conditions typically have a soil-to-water ratio of approximately 5.8:1 (assuming 30% porosity). Furthermore, in-situ soil particles are compacted and inhibit the entry of the oxidants into the particle matrix.

In-situ conditions present a unique set of obstacles relative to bench-scale conditions and the implementation of ISCO remediation in the field is much more complex than in the laboratory. Remediation requires the appropriate combination of injection pressures, volumes and flow rates; reagent type and concentration; and injection spacing – all intended to achieve a uniform distribution of reagents in the subsurface. These parameters have to be linked with the site conditions such as grain size, site stratigraphy, depth to water, etc. For most sites, including the FPC-TX site, actual in-place oxidant loading and concentrations will likely be lower than those in the study to address site conditions such as the presence of interbedded low-permeability soils and a shallow water table.

Finally, ISOTEC observed that the reduction in EDC/VOC concentrations in both the solid and aqueous phases was very limited for both the low-dose persulfate applications, but this was not the case for the low-dose MFR application (see pages 13-14 of the ISOTEC report in Appendix B). Given the site characteristics noted in the previous paragraphs, field applications of ISCO will mimic the low-dose applications. Since contaminant mass reduction typically comes from a cumulative effect of multiple low-dose applications (as opposed to one medium- or high-dose application), it does not appear that multiple low-dose applications of activated persulfate will lead to cumulative contaminant mass reduction. However, multiple low-dose applications of MFR should produce a cumulative contaminant mass reduction. Based on these conclusions, a field pilot study using MFR as the oxidant is recommended by ISOTEC.

4.2 Enhanced Bioremediation

FMC is currently performing a bench-scale treatability study to evaluate the bioremediation technology. FMC is using its EHC® technology which uses controlled-release, integrated carbon (as a nutrient source) and zero-valent iron (ZVI) as a reducing agent to stimulate the reductive dechlorination of chlorinated solvents such as EDC.

Site soil and groundwater samples were first composited (from the separate containers sent to FMC by PBW). A portion of the composited soil and groundwater was submitted to a laboratory for initial chemical characterization. The bench-scale test was set up as outlined in FMC's proposal contained in the work plan (PBW, 2012a). One EHC treatment microcosm and two control microcosms (groundwater and ambient) were prepared. Sacrificial jars (glass jars with Teflon-lined lids) were set up for the control and treatment microcosms. Two sizes of jars were used (250 mL and 1 L) to allow for sampling of additional parameters during the final sampling event. The groundwater control microcosms were filled with the composited groundwater to zero headspace and capped. The ambient control microcosms contained the homogenized soil (75g for the 250 mL jar; 300 g for the 1 L jar) and were filled with site groundwater to zero headspace and capped. The EHC microcosms were filled with the homogenized site soil, 0.5% EHC reagent (1.5 g for the 250 mL jar; 5.7 g for the 1 L jar), and site groundwater to zero headspace and capped. The mass of EHC was added based on the total mass of soil and groundwater in the microcosms. All microcosms were inverted several times to mix.

Time zero samples were collected from the control microcosm on the first day of the test. Samples will be collected from the control and EHC treatment microcosms at week 4, week 8, and week 12. Sample results will be evaluated at each step to determine the need for additional sampling events or termination of the study. FMC will submit a study report to PBW upon completion of the study. The results of the bench-scale bioremediation study will be reported via an addendum to this report.

4.3 Mass Removal

Gainco performed the mass removal study at well cluster P-56/P-57/RS-6, as described in their report contained in Appendix C. Per the work plan (PBW, 2012a), Gainco performed a three-phase test to determine whether SVE or high vacuum DPE technology is suitable for remediation of the site. The test apparatus consisted of a liquid ring pump connected to a 1-inch diameter PVC pipe (stinger) that was inserted into well P-57 (the "extraction well" in the context of this test). Stage 1 was performed by applying a vacuum in a step-wise fashion in well P-57 with the stinger approximately 9-10 feet above the water level and with the annular space between the stinger and well casing sealed. The duration of the test was 90 minutes and measurements of vacuum were taken from wells P-57, P-56, and temporary well TS-2 that was installed for the purposes of this study. Stage 2 of the study consisted of a short-term pump test performed with the stinger placed near the bottom of well P-57. Water-level measurements were taken from wells P-56 and TS-2 during the test to allow for estimation of aquifer properties. Stage 3 of the study evaluated DPE by applying a constant vacuum in well P-57 with the stinger below the water level and with the annular space between the stinger and the well casing sealed. Measurements of groundwater extraction rate, subsurface vacuum, volatile organic compound concentration (via a photoionization detector) were collected during the six-hour test.

The results of the study are included in the Gainco report contained in Appendix C, including tables, figures and graphs. The major conclusions of the study are:

1) The average mass of hydrocarbons removed was approximately ten times greater with high-vacuum DPE than with SVE alone (0.83 lb/hr for DPE versus 0.072 lb/hr for SVE). Although the low permeability of the soil at the site reduces overall effectiveness, the relatively high volatility of EDC and the other hydrocarbons present at the site make these contaminants viable candidates for remediation via DPE. SVE alone is not likely a suitable remedial technology for the site.
2) The hydrocarbon mass removal was low using SVE alone. Attempts to apply a high vacuum in well P-57 using SVE alone resulted in an increase in the water level above the well screen, precluding the removal of soil vapor using this method. These results are likely due to the relatively low permeability of the soils present at the site. As mentioned above, SVE alone is not likely a suitable remedial technology for the site.
3) The radius of influence (ROI) of the vacuum in the subsurface predicted by the tests was 7.5 feet for SVE and 11.5 feet for DPE.
4) The average groundwater recovery rate during the pump test (Stage 2) was 0.57 gallons per minute (gpm). The average groundwater recovery rate during the DPE test (Stage 3) was 0.49 gpm.
5) The hydraulic conductivity of the Zone A sand interval estimated by the pump test (Stage 2) was 1.34×10^{-2} cm/sec (38 ft/day). This estimate is approximately one order of magnitude greater than previous estimates of the hydraulic conductivity of the Zone A sand at this location and at other locations at the site.

Location in sand channel?

Based on these conclusions, DPE remains a potentially viable remediation alternative for the site. Further evaluation of DPE should be conducted by performing a pilot-scale test of longer duration (e.g., three days).

5.0 CONCLUSIONS

5.1 ISCO

The results of post-test chemical analyses of the soil and groundwater indicate that all three ISCO reagents were effective at treating EDC and other VOCs detected at the site. The maximum EDC and total VOC reduction was greater than 99% in both the solid and aqueous phases. Destruction of EDC was also greater at the higher reagent doses, as would be expected.

Iron and manganese concentrations in soil and groundwater are important catalysts in the FMR and persulfate reactions that result in EDC/VOC destruction. The total iron, ferrous iron and manganese concentrations in site groundwater are below the minimum concentrations necessary for proper activation of the reagents. Therefore, external catalyst would be required for field application of these reagents. Also, the background total organic carbon (TOC) concentrations in site soil and groundwater are expected to exert a moderate to high oxidant demand (oxidant scavenging).

A limitation of the study is that a bench-scale study only evaluates the oxidation "chemistry" of the various oxidants as it relates to site contaminants and certain site characteristics. For the current study performed by ISOTEC, the oxidants were successful in reducing EDC and other VOC concentrations using site soil and groundwater. However, in-situ conditions present a unique set of obstacles relative to bench-scale conditions and the implementation of ISCO remediation in the field is much more complex than in the laboratory. Remediation requires the appropriate combination of injection pressures, volumes and flow rates; reagent type and concentration; and injection spacing – all intended to achieve a uniform distribution of reagents in the subsurface. These parameters have to be linked with the site conditions such as grain size, site stratigraphy, depth to water, etc. For most sites, including the FPC-TX site, actual in-place oxidant loading will likely be lower than in the study to address site conditions such as the presence of interbedded low-permeability soils and a shallow water table.

Finally, ISOTEC observed that the reduction in EDC/VOC concentrations in both the solid and aqueous phases was very limited for both the low-dose persulfate applications, but this was not the case for the low-dose MFR application. Given the site characteristics, field applications of ISCO will mimic the low-dose applications. Since contaminant mass reduction typically comes from a cumulative effect of multiple low-dose applications (as opposed to one medium- or high-dose application), it does not appear that multiple low-dose applications of activated persulfate will lead to cumulative contaminant mass reduction. However, multiple low-dose applications of MFR should produce a cumulative contaminant mass reduction. Based on these conclusions, a field pilot study using MFR as the oxidant is recommended by ISOTEC.

5.2 Mass Removal

The three-stage mass removal pilot test evaluated SVE alone and DPE as potential remedial technologies for the site. The study results indicated that SVE alone is not viable at this site due to the relatively low permeability of the soils at the site. In the pilot test, the application of a high vacuum increased the groundwater level in the well, precluding the removal of vapor phase contamination from the vadose zone.

The average mass of hydrocarbons removed was approximately ten times greater with high-vacuum DPE than with SVE alone. Although the low permeability of the soil at the site reduces overall effectiveness, the relatively high volatility of EDC and the other hydrocarbons present at the site make these contaminants viable candidates for remediation via DPE. Further evaluation of DPE should be conducted by performing a pilot-scale test of longer duration (e.g., three days).

6.0 REFERENCES

C-K, 1995. C-K Associates, Inc. Supplemental RCRA Facility Investigation. Prepared for Formosa Plastics Corporation, Texas. June. Revised May 1998.

Pastor, Behling & Wheeler, LLC (PBW), 2012a. Bench-Scale Treatability Testing Work Plan. Prepared for Formosa Plastics Corporation, Texas. July.

Pastor, Behling & Wheeler, LLC (PBW), 2012b. AOC Characterization Report. Prepared for Formosa Plastics Corporation, Texas. November.

Tetra Tech, 2010. Final Risk Management Plan. Prepared for Formosa Plastics Corporation, Texas. April 30.

Tetra Tech, 2012. Areas of Concern Characterization Work Plan. Prepared for Formosa Plastics Corporation, Texas. May 4.

TABLES

TABLE 1. ISCO TESTS DATA SUMMARY – EDC AND VOCs

AQUEOUS PHASE (concentrations in ug/L)				
	EDC	TOTAL VOCs	EDC REDUCTION	VOC REDUCTION
INITIAL CONDITIONS	1,280,000	1,408,780	--	--
MODIFIED FENTON'S REAGENT TEST				
Control	470,000	519,980	--	--
Low Dose	185,000	208,760	60.64%	59.85%
Medium Dose	30,600	35,114	93.49%	93.25%
High Dose	8,190	10,676	98.26%	97.95%
ALKALI-ACTIVATED SODIUM PERSULFATE TEST				
Control	652,000	700,690	--	--
Low Dose	497,000	524,220	23.77%	25.19%
Medium Dose	86,100	92,888	86.79%	86.74%
High Dose	243	667.86	99.96%	99.90%
HEAT-ACTIVATED SODIUM PERSULFATE TEST				
Control	746,000	806,720	--	--
Low Dose	568,000	612,240	23.86%	24.11%
Medium Dose	2,750	38,372	99.63%	95.24%
High Dose	200	16,901	99.97%	97.90%
SOLID PHASE (concentrations in mg/Kg)				
	EDC	TOTAL VOCs	EDC REDUCTION	VOC REDUCTION
INITIAL CONDITIONS	44.9	47.4	--	--
MODIFIED FENTON'S REAGENT TEST				
Control	64.10	67.1	--	--
Low Dose	16.7	17.7	73.95%	73.66%
Medium Dose	0.011	0.01	99.98%	99.98%
High Dose	0.0063	0.01	99.99%	99.99%
ALKALI-ACTIVATED SODIUM PERSULFATE TEST				
Control	116	122.52	--	--
Low Dose	124	129.01	Increase	Increase
Medium Dose	12.8	13.63	88.97%	88.88%
High Dose	0.063	0.06	99.85%	99.95%
HEAT-ACTIVATED SODIUM PERSULFATE TEST				
Control	74	77.24	--	--
Low Dose	75	78.40	Increase	Increase
Medium Dose	0.487	2.17	99.34%	97.19%
High Dose	0.053	1.01	99.93%	98.69%

Notes:

1) See ISOTEC report (Appendix B) for complete data and discussion.

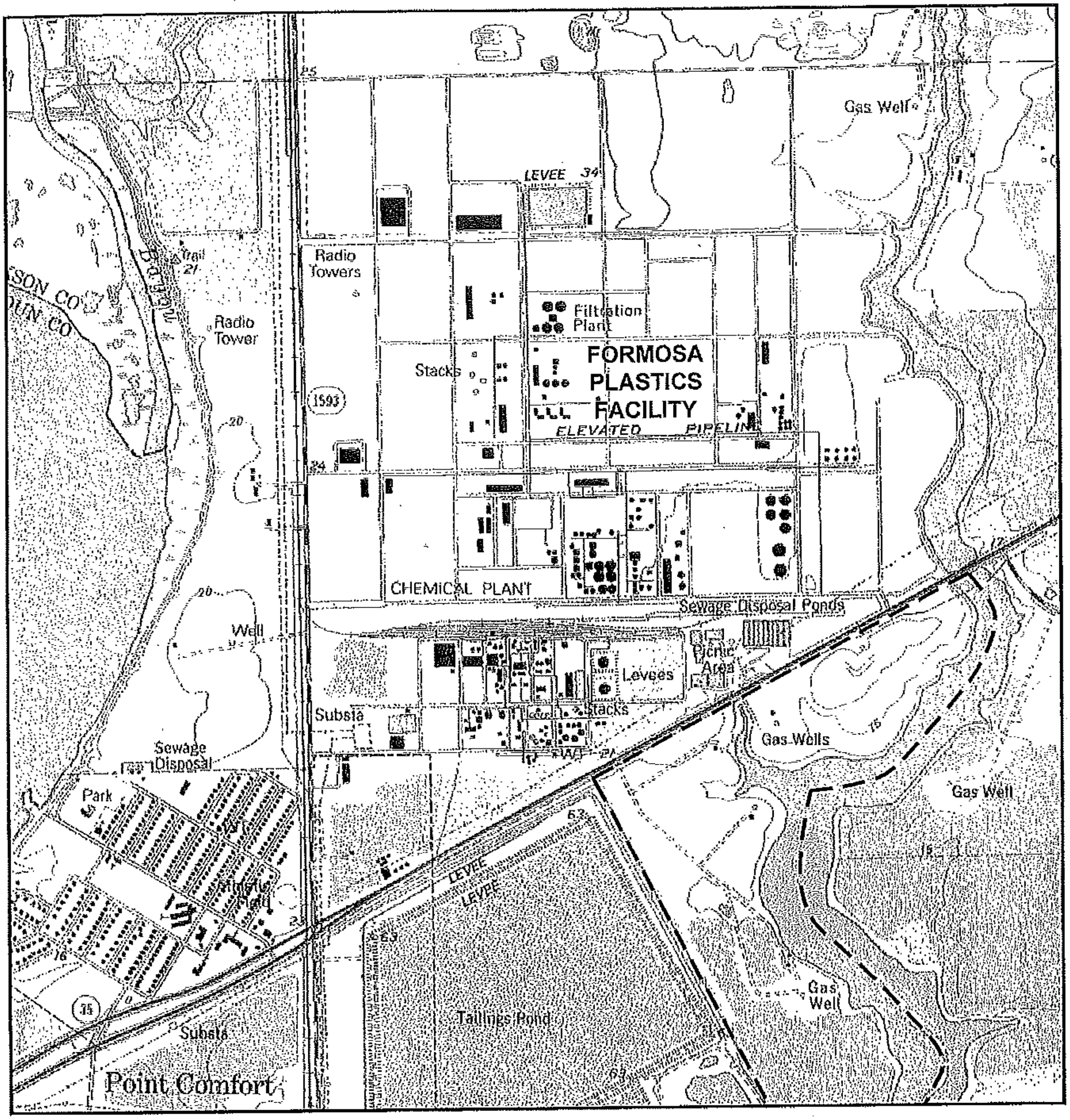
TABLE 2. ISCO TESTS DATA SUMMARY – GENERAL PARAMETERS

AQUEOUS PHASE (concentrations in ug/L)										
	pH (SU)	ORP (mV)	TDS (mg/L)	Fe2+ (ug/L)	Sulfate (SO_4) (ug/L)	TOC (ug/L)	Total Iron (ug/L)	Manganese (ug/L)	Alkalinity (ug/L)	Nitrate (ug/L)
INITIAL COND.	6.55	-125	9,150	4,960	378,000	8,540	8,710	7,930	606,000	ND (<500)
MODIFIED FENTON'S REAGENT TEST										
Control	6.51	185	5,940	< 40	--	--	--	--	--	--
Low Dose	6.63	182	6,286	< 40	--	--	--	--	--	--
Medium Dose	6.90	189	8,220	< 40	--	--	--	--	--	--
High Dose	7.15	203	11,070	< 40	--	--	--	--	--	--
ALKALI-ACTIVATED SODIUM PERSULFATE TEST										
Control	6.6	46	10,880	--	--	--	--	--	--	--
Low Dose	11.36	-159	18,340	--	--	--	--	--	--	--
Medium Dose	12.06	-199	48,500	--	--	--	--	--	--	--
High Dose	12.25	-211	91,740	--	--	--	--	--	--	--
HEAT-ACTIVATED SODIUM PERSULFATE TEST										
Control	6.57	34	11,170	--	--	--	--	--	--	--
Low Dose	6.18	48	19,040	--	--	--	--	--	--	--
Medium Dose	6.02	57	36,150	--	--	--	--	--	--	--
High Dose	5.37	99	55,300	--	--	--	--	--	--	--
SOLID PHASE (concentrations in mg/Kg)										
						TOC (mg/Kg)	Total Iron (mg/Kg)	Manganese (mg/Kg)		
INITIAL COND.	--	--	--	--	--	1,190	5,640	136	--	--

Notes:

1) See ISOTEC report (Appendix B) for complete data and discussion.

FIGURES



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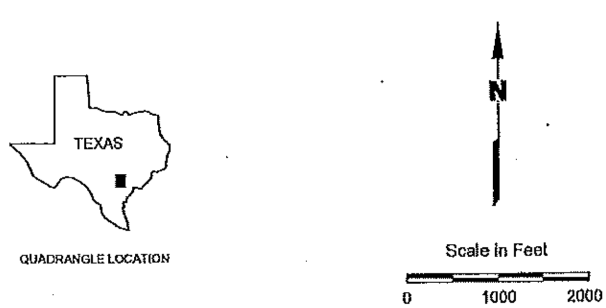


FORMOSA PLASTICS CORPORATION

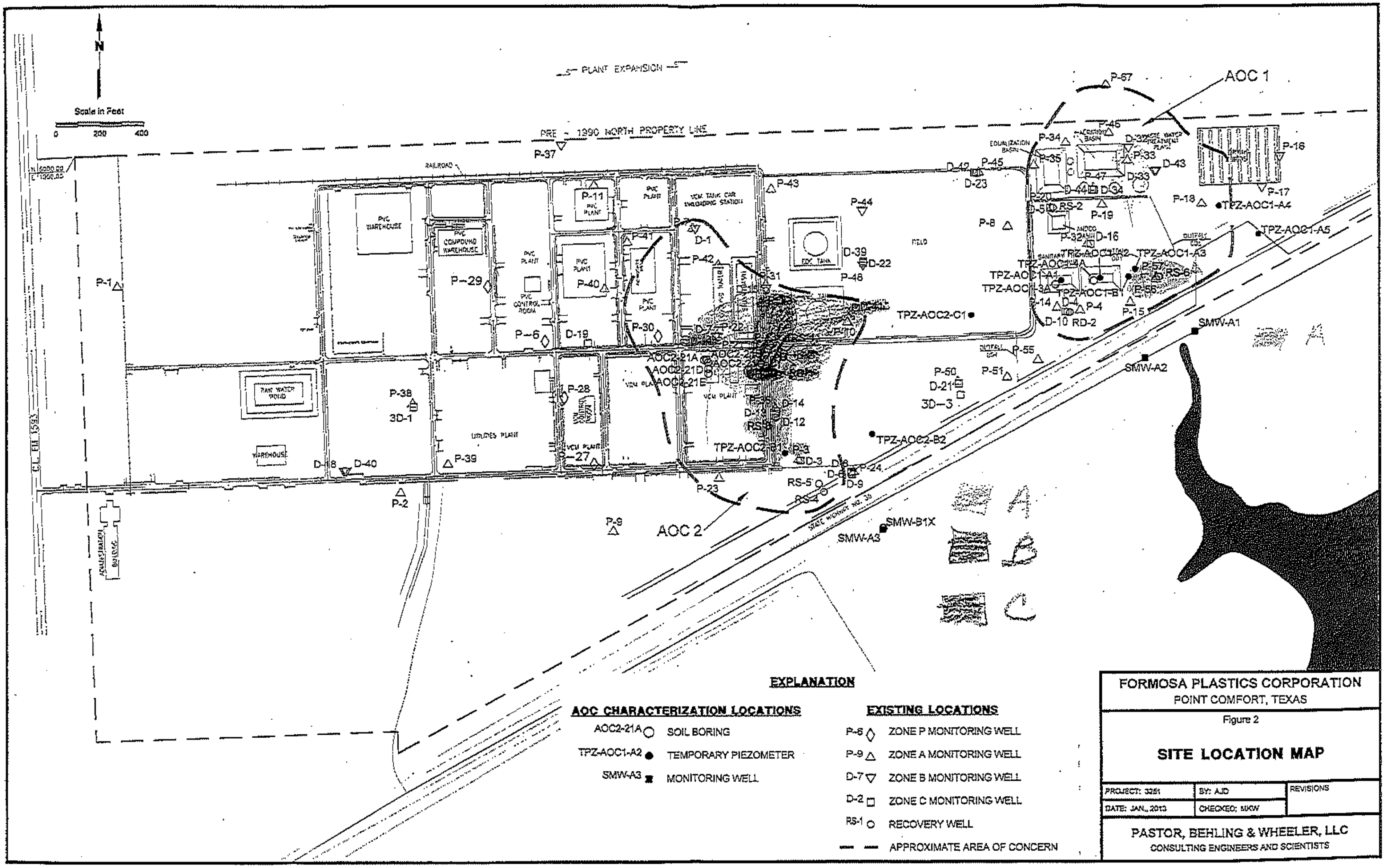
Figure 1

AREA LOCATION MAP

PROJECT: 3251	BY: AJD	REVISIONS
DATE: JAN., 2013	CHECKED: MKW	

PASTOR, BEHLING & WHEELER, LLC
CONSULTING ENGINEERS AND SCIENTISTS

Source:
Base map from Point Comfort, Texas 7.5 min. U.S.G.S. quadrangle (1995).


N
Scale in Feet
0 200 400
PLANT EXPANSION
PRE - 1990 NORTH PROPERTY LINE
AOC 1
AOC 2
PVC WAREHOUSE
PVC COMPOUND WAREHOUSE
PVC PLANT
PVC CONTROL ROOM
VCM TANK CAR UNLOADING STATION
EDC TANK
UTILITIES PLANT
VCM PLANT
RAW WATER POND
WAREHOUSE
ADMINISTRATION BUILDING
STATE HIGHWAY NO. 35
TPZ-AOC2-C1
TPZ-AOC2-B2
TPZ-AOC2-B1
TPZ-AOC1-A4
TPZ-AOC1-A5
TPZ-AOC1-A3
TPZ-AOC1-A1
TPZ-AOC1-B1
SMW-A1
SMW-A2
SMW-A3
SMW-B1X
AOC2-21A
AOC2-21D
AOC2-21E
EXPLANATION
AOC CHARACTERIZATION LOCATIONS
AOC2-21A SOIL BORING
TPZ-AOC1-A2 TEMPORARY PIEZOMETER
SMW-A3 MONITORING WELL
EXISTING LOCATIONS
P-6 ZONE P MONITORING WELL
P-9 ZONE A MONITORING WELL
D-7 ZONE B MONITORING WELL
D-2 ZONE C MONITORING WELL
RS-1 RECOVERY WELL
APPROXIMATE AREA OF CONCERN
FORMOSA PLASTICS CORPORATION
POINT COMFORT, TEXAS
Figure 2
SITE LOCATION MAP
PROJECT: 3251
BY: AJD
REVISIONS
DATE: JAN., 2013
CHECKED: MKW
PASTOR, BEHLING & WHEELER, LLC
CONSULTING ENGINEERS AND SCIENTISTS

APPENDIX A

Boring Log for TS-1

FORMOSA PLASTICS CORPORATION, TEXAS	Log of Boring: TS-1 (a,b,c,d)

201 FORMOSA DRIVE POINT COMFORT, TEXAS	Completion Date:	9/4/2012	Drilling Method:	GeoProbe-Sonic
	Drilling Company:	Walker-Hill	Borehole Diameter (in.):	4"
	Driller:	Sammy V. Barnes, Jr.	Total Depth (ft):	20'
	Driller's License:	59265	Northing:	13441469.579
PBW PROJECT No.: 3255	Field Supervisor:	Kevin Dworsky	Easting:	2758180.838
	Sampling Method:	4" Hollow Core	Ground Elev. (ft AMSL):	NA

Depth (ft)	Well Materials	PID (ppm-v)	(ft/ft) Recovery	USCS	Lithologic Description
0–2.9			9.8/10.0	OL	0.0-2.9 - Sandy clay, black, abundant organic material, stiff, homogeneous, diffused boundary, moist, hard, medium plasticity
2.9–11.9				CL	2.9-11.9 - Sandy clay, reddish tan, abundant small caliche nodules on top half of section, some black staining, some gray clay lenses, fine grained sand, clear boundary, moist, hard, medium plasticity
11.9–13.6			10.0/10.0	SM	11.9-13.6 - Silty sand, tan, abundant silt, some reddish clay nodules, traces of organic material, clear boundary, wet, soft, rapid dilatancy, no plasticity
13.6–20.0				CH	13.6-20.0 - Silty clay, reddish tan, traces of fine sand, some black staining, some small caliche nodules, some gray clay veins, moist, very hard, high plasticity

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

PBW

Pastor, Behling & Wheeler, LLC
620 E. Airline
Victoria, TX 77901
Tel (361) 573-6442 Fax (361) 573-6449

Notes:

APPENDIX B

ISOTEC Report - ISCO

BENCH SCALE TREATABILITY STUDY REPORT

FORMOSA PLASTICS CORPORATION
POINT COMFORT, TEXAS

JANUARY 11, 2013

PREPARED FOR

PASTOR, BEHLING & WHEELER, LLC
620 E. AIRLINE ROAD
VICTORIA, TEXAS 77901

ISOTEC PROJECT NO. 901132

In-Situ Oxidative Technologies, Inc.
6452 Fig Street, Suite C
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WWW.INSITUOXIDATION.COM

SBA Certified Small Business

TABLE OF CONTENTS

TABLES

ATTACHMENTS

ACRONYMS

ASP	Activated sodium persulfate
ASP-alk	Alkali activated sodium persulfate
ASP-heat	Heat activated sodium persulfate
COCs	Constituents of concern
expt	Experiment
g	gram
g/kg	Grams per kilogram
GW	Groundwater
IAL	Integrated Analytical Laboratories, LLC
ISCO	In-situ chemical oxidation
ISOTEC	In-Situ Oxidative Technologies, Inc.
Lbs	Pounds
MFR	Modified Fenton's Reagent
mg/kg	Milligrams per kilogram
mg	milligram
ml	milliliter
mV	milli volt
NaOH	Sodium hydroxide
$Na_2S_2O_8$	Sodium persulfate
ND	Non detect concentration
PBW	Pasto, Behling & Wheeler, LLC
ppm	Parts per million
TDS	Total dissolved solids
TOC	Total organic carbon
TOD	Total oxidant demand
ug/kg	Micrograms per kilogram
µg/L	Micrograms per liter
VOC	Volatile organic compound

1.0 EXECUTIVE SUMMARY

In-Situ Oxidative Technologies, Inc. (ISOTEC[SM]) was retained by Pastor, Behling & Wheeler, LLC (PBW) to conduct an in-situ chemical oxidation (ISCO) bench-scale laboratory treatability study (study) on soil and groundwater (GW) samples collected from the Formosa Plastics Corporation (Formosa) site located in Point Comfort, Texas. The target constituents for the study are volatile organic compounds (VOCs), and the constituent of concern (COC) at the site is 1,2-dichloroethane (EDC). Reagents evaluated during the study were modified Fenton's reagent (MFR) and sodium persulfate activated with alkali (ASP-alk) and heat (ASP-heat). The objective of the bench scale study was to evaluate the potential effectiveness of MFR, ASP-alk and ASP-heat in the treatment of EDC impacted soil and groundwater at the site. In addition, total oxidant demand (TOD) for ASP (measured as sodium persulfate) were also evaluated. TOD for MFR was not performed as consumption of hydrogen peroxide (by the activating agent in the MFR reagent to generate hydroxyl free radicals) is nearly 100% in most cases.

PBW collected soil and GW samples from the site and shipped them to ISOTEC for use during the treatability study. Prior to initiating the study, soil and groundwater were first composited, and a portion of the composited soil and composited GW was then collected and submitted to Integrated Analytical Laboratories, LLC (IAL) for various chemical analyses to collect initial characteristics data of the samples.

The remaining composited soils and GW were prepared into a slurry form by mixing the composited soil with the GW at a soil-to-water ratio of 2:1 by weight. All experiments were performed on the 2:1 slurry samples. A total of three experiments were performed, one for each reagent. For each test, a total of four reactors were set up with one reactor serving as the "control" and the remaining three served as "treatment" reactors. Each reactor consisted of the exact same quantity of composited soil and groundwater prior to the start of the experiments. Reagents were evaluated at three doses as shown in the table below. The experiments were quenched upon the completion of the tests. All reactors were separated into aqueous and solid phases and submitted for various chemical analyses on each phase.

Experiment Summary

Oxidant dose	MFR-test	ASP-alk-test	ASP-heat-test
Low dose	6.6 g/kg	6 g/kg	6 g/kg
Medium dose	33.3 g/kg	30 g/kg	30 g/kg
High dose	66 g/kg	60 g/kg	60 g/kg
Test Duration	3 days	10 days	1 day

Note: Oxidant doses are presented as grams of oxidant per kilogram of soil being tested.

Results indicate that all three reagents were effective in treating EDC as well as other VOCs detected at the site. Summary results are presented below.

- Using MFR, EDC was treated from 470,000 micrograms per liter (μg/L) to 185,000 μg/L following the low dose treatment, and further down to 30,600 μg/L (medium dose) and 8,190 μg/L (high dose) in the aqueous phase, and from 64.1 milligrams per kilogram (mg/kg) to 16.7 mg/kg (low dose) and 0.0063 mg/kg (high dose) in the solid phase. VOC reductions achieved were 60% (low dose), 93% (medium dose) and 98% (high dose) in the aqueous phase and 74% (low dose) and >99% (medium and high doses) in the solid phase.
- Using ASP-alk, EDC was treated from 652,000 μg/L to 497,000 μg/L (low dose), 86,100 μg/L (medium dose) and 243 μg/L (high dose) in the aqueous phase. In the solid phase, EDC was treated from 116 mg/kg to 12.8 mg/kg (medium dose) following a slight increase with the low dose application and further down to 0.06 mg/kg (high dose). VOC reductions achieved were 25% (low dose), 87% (medium dose) and >99% (high dose) in the aqueous phase and 89% (medium dose) and >99% (high doses) in the solid phase. TOD analyses indicated 26%-57% consumption of sodium persulfate ($Na_2S_2O_8$) applied during the 10 day test period with an oxidant demand of 3.42 g/kg for the low dose, 9 g/kg for the medium dose and 15.6 g/kg for the high dose.
- Using ASP-heat, a similar EDC/VOC reduction pattern to that of ASP-alk was observed. EDC was treated from 746,000 μg/L to 568,000 μg/L (low dose), 2,750 μg/L (medium dose) and 200 μg/L (high dose) in the aqueous phase. In the solid phase, EDC was treated from 74 mg/kg to 0.487 mg/kg (medium dose) following a slight increase with the low dose application and further down to 0.05 mg/kg (high doses). VOC reduction achieved were 25% (low dose), 95% (medium dose) and 98% (high dose) in the aqueous phase and 97% (medium dose) and 99% (high doses) in the solid phase. TOD analyses indicated 53%-72% consumption of $Na_2S_2O_8$ applied during the 1 day test period with an oxidant demand of 4.32 g/kg for the low dose, 18.9 g/kg for the medium dose and 31.8 g/kg for the high dose.
- One observation of the bench study data is unique and important. The reduction in concentration in both solid and aqueous phases was very limited in both low-dose persulfate applications, while the MFR low-dose application showed a 61% and 74% VOC reduction for aqueous and solid phase, respectively. Total contaminant mass reduction comes from a cumulative effect of multiple low-dose applications, as opposed to one large medium-dose application; due primarily to field injection limitations of reagent volume and concentration. It does not appear that multiple low-dose applications of activated persulfate will lead to a cumulative mass reduction, since individual low-dose applications are

relatively ineffective. However, multiple low-dose applications of MFR should produce a cumulative mass reduction.

2.0 BENCH SCALE STUDY OBJECTIVES

The objectives of the bench scale study are to:

- Evaluate the treatment effectiveness of MFR, ASP-alk and ASP-heat in the treatment of VOCs, primarily EDC.
- Determine the total oxidant demand (TOD) for ASP-alk and ASP-heat.

3.0 SAMPLE COLLECTION AND PREPARATION

PBW collected soil (TS-1) and GW (P-56) samples on Sept. 5, 2012 from the site and shipped them to the ISOTEC research facility for use during the treatability study. The samples were stored at <4°C during the shipment and at ISOTEC's facility until commencement of each test.

Prior to initiating the study, the soil and groundwater samples were composited. A portion of the composited soils and groundwater was collected for initial characterization. This included analyses of VOCs, total organic carbon (TOC), total iron and total manganese on soil and GW samples, and alkalinity, ferrous iron, nitrate, sulfate and total dissolved solids on the GW sample only.

The experiment samples were prepared by mixing the composited soil with the groundwater at a 2:1 soil to groundwater ratio by weight. The 2:1 ratio was selected to represent a soil matrix that resembles the saturated subsurface with groundwater pore volume representative of 33% porosity. The experiment samples were used to perform various experiments to evaluate the effectiveness of MFR, ASP-alk and ASP-heat.

All samples were submitted to IAL for analyses. TOD analysis was performed internally at the ISOTEC laboratory along with pH, oxidation-reduction potential (ORP) and total dissolved solids (TDS) measurements.

4.0 EXPERIMENTAL PROCEDURES

The bench-scale treatability study consisted of MFR-test, ASP-alk-test and ASP-heat-test. In general, each test comprised of the following 4 steps:

1. Reagent Identification,
2. Establishing experimental control,
3. Experimental setup, and
4. Sample analysis.

4.1 Reagent Identification

In accordance to the Treatability Study Proposal, MFR and ASP were to be evaluated in the study. Both MFR and ASP consisted of an oxidant and an activating agent. For MFR, the oxidant used is stabilized hydrogen peroxide (H_2O_2) and the activating agent used is ISOTEC's patented Catalyst Series 4260 (Cat-4260), which is a circum-neutral pH (e.g. 5-8) organometallic complex (chelated iron) with high mobility within the subsurface. For ASP, the oxidant used is sodium persulfate ($Na_2S_2O_8$) and the activating agent used is sodium hydroxide (NaOH) for ASP-alk, and heat (60°C) for ASP-heat.

4.2 Establishing Experimental Controls

An experimental "control" sample was set up during each experiment to document the following:

- Reduction or changes in concentrations of the target constituents due to sample dilution by reagent volumes injected.
- Reduction in concentrations of the target constituents due to volatilization caused by room temperature test conditions for MFR and ASP-alk, and the heated conditions for ASP-heat.

The "control" sample was set up exactly the same way, remained at, and was subject to the same conditions as the associated "treatment" reactors. However, the "control" reactor received distilled water (DI) instead of reagent (see Section 4.4 below).

4.3 Experimental Setup

Each experiment was set up in four reactors, one served as the "control" reactor (see Section 4.2 above) and the remaining three reactors as "treatment" reactors to receive MFR and ASP reagents at three dosages (low, medium and high) by weight of soil in the slurry being tested.

The experiments were performed in 250 milliliter (ml) VOC-tight glass jars sealed with screw top caps fitted with Teflon septa to facilitate reagent injection and prevent contaminant volatilization during the experiments. Exactly 150 grams (g) of 2:1 slurry

(100 g of soil and 50 ml of groundwater) was introduced into each reactor. The reactors were set up in duplicates, with one set used for VOC analysis and the second set used for pH, ORP, TDS measurements and TOD monitoring of $Na_2S_2O_8$ concentrations.

4.4 Reagent Applications

4.4.1 MFR-test

For reagent application, a predetermined amount of MFR was injected into each "treatment" reactor as incremental doses and DI water was used to compensate the differences in reagent volumes applied between reactors. The final oxidant (H_2O_2) concentrations were 6.6 g/kg (low), 33.3 g/kg (medium) and 66 g/kg (high) by weight of soil in the slurry sample being tested.

The multiple dosage approach (incremental approach) was used to increase treatment efficiency, minimize gas formation (preventing volatilization) and the resulting pressure buildup. For this study, two, four and six injections were performed to achieve the final oxidant concentrations in low dose, medium dose and high dose reactors, respectively. A time gap of approximately eight hours was maintained between dosages. All reactors (control and treatment) were left under room temperature conditions and inverted exactly 10 times daily to gain maximum contact between the reagent and the sample matrix. The duration of the experiment was three days.

4.4.2 ASP-alk-test

The predetermined amount of $Na_2S_2O_8$ was applied into each "treatment" reactor in a single batch and DI water was used to compensate the difference in reagent volumes applied between reactors. The final oxidant ($Na_2S_2O_8$) concentrations were 6 g/kg (low dose), 30 g/kg (medium dose) and 60 g/kg (high dose) by weight of soil in the slurry sample being tested. The "control" reactor in each experiment received an equivalent volume of distilled water instead of reagent. Alkali activation was achieved by raising and maintaining the pH value of the sample contents in each "treatment" reactor to between 11 and 12 standard unit (su) via addition of NaOH. All reactors (control and treatment) were left under room temperature conditions and inverted exactly 10 times daily to gain maximum contact between the reagent and the sample matrix. The duration of the experiment was 10 days.

4.4.3 ASP-heat-test

Similar to the ASP-alk-test, the predetermined amount of $Na_2S_2O_8$ was applied into each "treatment" reactor in a single batch and DI water was used to compensate the difference of reagent volumes applied between reactors. The final oxidant ($Na_2S_2O_8$) concentrations were 6 g/kg (low dose), 30 g/kg (medium dose) and 60 g/kg (high dose) by weight of soil in the slurry sample being tested. The "control" reactor received an equivalent volume of distilled water instead of reagent. Heat activation was achieved by placing all reactors (control and treatment) of both sets in a water bath with warm water to raise and maintain the temperature of the sample contents at 60°C. The duration of the experiment was one day to minimize the VOC loss under a raised temperature.

For all three tests, a quenching agent (i.e. bovine catalase for peroxide and sodium thiosulfate for sodium persulfate) was injected into each reactor to terminate the reaction at the end of the experiments. Reactors were quenched (even if all the oxidant was not consumed) to minimize COC loss associated with volatilization under room temperature or heated test conditions.

TOD analysis was performed in the corresponding duplicates internally at ISOTEC. The TOD was determined by measuring the initial oxidant measurements (i.e. time = 0 days) collected immediately after introducing the oxidant into each reactor to obtain a baseline starting oxidant concentration. The residual oxidant concentration was obtained at the specific quenching period. TOD is determined from the difference of initial oxidant concentration and the final oxidant concentration. For ASP, TOD was reported as "g/kg" of sodium persulfate. Sodium persulfate concentrations were measured using a CHEMetrics colorimetric testing kit. Final pH, ORP and TDS values were measured using a Myron test kit in the corresponding duplicates.

4.5 Analytical Sample Collection and Analyses

Upon experiment completion, sample contents in each reactor (control and treatment) were separated into aqueous and solid phases. Then analytical samples were collected from each phase and submitted for various analyses as indicated in the table below.

Laboratory Analytical Parameters Summary

Parameters	Initial Characteristics		MFR-test		ASP-alk-test		ASP-heat-test	
	GW	Soil	Aqueous phase	Solid phase	Aqueous phase	Solid phase	Aqueous phase	Solid phase
VOCs	x	x	x	x	x	x	x	x
Ferrous iron	x		x					
Total iron	x	x						
Total manganese	x	x						
Alkalinity	x							
TOC	x	x						
TDS	x							
Sulfate	x							
Nitrate	x							

IAL performed all chemical analyses associated with the bench-scale treatability study. The VOC analyses was performed using Method SW-846 624 (GW)/8260B (soil), TOC analysis was performed using EPA method modified Lloyd Kahn (soil)/5310C (GW), and total iron and manganese analysis was performed using EPA method 6020, ferrous iron using SM20 3500FeB, alkalinity using 2320B, nitrate using 4500NO3F and TDS using 2540C. Laboratory analytical data packages including chains of custody, and internal laboratory custody chronicle are included as Attachment A.

5.0 RESULTS AND DISCUSSION

Detailed bench-scale testing results (including the initial characteristics analyses and experiment results) are presented in Tables 1 through 4. Laboratory analytical data packages are provided in Attachment A. Initial characteristics results are discussed in Section 5.1 and experiment results are discussed in Sections 5.2.

5.1 Initial Characteristics

Initial characteristics results are presented in Table 1.

In the GW sample (P-56), EDC, the primary site COC, was detected at 1,280,000 µg/L. Another 10 VOCs including chloroform (81,600 µg/L), vinyl chloride (13,300 µg/L) and 1,1-DCA (8,400 µg/L) were also detected in the sample resulting in a cumulative VOC concentration at 1,408,780 µg/L. Total iron and manganese were detected at 8,710 µg/L and 7,930 µg/L, respectively, and ferrous iron was found at 4,960 µg/L. Based on ISOTEC's past experience, iron concentrations in the aqueous phase should be greater than 25,000 µg/L (typical range should be 25,000 to 100,000 µg/L) to serve as effective Fenton's catalyst and greater than 150,000 µg/L to serve as effective sodium persulfate catalyst. Manganese concentrations greater than 25,000 µg/L also have potential to promote Fenton-like reactions. TOC was detected at 8,540 µg/L. Alkalinity and sulfate were detected at 606,000 µg/L and 378,000 µg/L, respectively. Nitrate was found at a non-detectable (ND) level (<500 µg/L).

In the soil sample (Soil Comp), EDC was detected at 44.9 mg/kg. Other VOCs detected were chloroform at 2.1 mg/kg and tetrachloroethene (PCE) at 0.4 mg/kg resulting in a total VOC concentration of 47.4 mg/kg. Total iron and manganese were found to be 5,640 mg/kg and 136 mg/kg, respectively. Iron and manganese are present in soils as mostly oxyhydroxides and may promote some Fenton-like reactions, although they are generally unavailable to act as effective catalysts and can potentially result in oxidant wastage. Alkalinity, nitrate, ferrous iron, sulfate and TDS were not analyzed. TOC was detected at 1,190 mg/kg.

TOC in both soil and groundwater will consume oxidants and higher TOC means greater competition for the oxidants, which can result in significant oxidant scavenging. The TOC levels detected in site soils (1,190 mg/kg) and GW (8,540 µg/L) are expected to exert a moderate to high oxidant demand. Iron in its dissolved form, especially ferrous iron, present in groundwater is known to activate sodium persulfate and hydrogen peroxide. As noted previously, iron levels in the groundwater (i.e. 8,710 µg/L for total dissolved iron and 4,960 µg/L for ferrous iron) are lower than the minimum iron concentration requirement for proper activation of sodium persulfate and hydrogen peroxide. Therefore, external catalyst will be needed during field application of MFR and ASP.

5.2 Experiment Results

COC treatment effectiveness is evaluated by comparison of "treated" sample data with the associated "control" sample data. A comparison between the "initial" and "control" data was not made because the analyses were performed on different types of samples (i.e. the "initial" were soil or GW samples, and "control" samples were slurry samples separated into solid and aqueous phases for analyses). However, since the "initial" and "control" samples were both untreated samples, they generally contain similar levels of contamination when sample materials are uniform. The "initial" samples typically have a higher COC concentration compared to "control" since the "control" samples are diluted after addition of DI water and are also subject to the room or heated temperature test conditions similar to the "treated" samples (Section 4.4). *[It should be noted that all three "control" samples contained higher VOC levels in the solid phase than the initial soil sample (i.e. Soil Comp). This anomaly is most likely due to heterogeneous nature of the soil samples, which made it almost impossible to produce uniform samples for all the tests and could cause fluctuations in analytical results. The control samples were also mixed with site water containing high VOC concentrations and submitted to the experiment conditions.]* As discussed in Section 4.2, a "control" sample was set up for each test to document COC concentration changes due to addition of reagents and VOC loss under the room temperature or heated test conditions. The "control" samples were prepared in the same manner and underwent the same conditions as the corresponding "treated" samples but received zero dosage of reagent. Therefore, the differences in contaminant concentrations between "treated" samples and the associated "control" sample best represent the treatment effectiveness and the effectiveness of each reagent is evaluated by comparison of "treated" sample data with the associated "control" sample data.

For discussion purpose, all ND values are assumed to be equal to zero in the contaminant reduction calculation. As discussed previously, three reagent doses of MFR (6.6 g/kg, 33.3 g/kg, & 66 g/kg of hydrogen peroxide, respectively, for low, medium and high doses) and three reagent doses of ASP (6 g/kg, 30 g/kg, & 60 g/kg of sodium persulfate, respectively, for low, medium and high doses) were evaluated. Results are presented in Tables 2, 3 and 4 and discussed below for each area.

Results indicate that all three reagents were effective in treating VOCs including EDC with maximum reduction achieved by greater than 97% in the aqueous phase and greater than 99% in the solid phase. Detailed discussions are provided below for each test.

5.2.1 MFR-test (Table 2)

A decreasing trend in VOC concentrations is evident as reagent doses increased in both solid and aqueous phases. In the solid phase, EDC was reduced from 64.1 mg/kg to 16.7 mg/kg (74% reduction) following the low dose application. It was further reduced to

0.01 mg/kg (medium dose) and 0.006 mg/kg (high dose), an equivalent 99.9% reduction for both doses. In the aqueous phase, EDC concentrations decreased from 470,000 µg/L to 185,000 µg/L (low dose), 30,600 µg/L (medium dose) and 8,190 µg/L (high dose), an equivalent 60%, 93% and 98% reduction.

Similar to EDC, VOC reductions achieved were 73.7% (low dose) and 99.9% (medium and high doses) in the solid phase, and 59.9% (low dose), 93.3% (medium dose) and 98.0% (high dose) in the aqueous phase.

TOD was not evaluated for MFR. In the MFR process, hydrogen peroxide consumption is mainly associated with generation of hydroxyl free radicals (the main agent to attack the organic compounds) through ISOTEC catalyst (the activating agent). The activation of hydrogen peroxide by ISOTEC catalyst is very quick (within hours) and, in most cases very efficient resulting in a nearly 100% consumption of hydrogen peroxide, regardless of the amount of soil or contaminants present.

Final pH ranged between 6.63 and 7.15 with a control value of 6.51. ORP values were between 182 mV and 203 mV with a control value of 185 mV, and TDS ranged between 11 µg/L and 8,220 µg/L with a control value of 5,940 µg/L. Ferrous iron was found at ND (<40 µg/L) in all treatment reactors as well as the control reactor.

5.2.2 ASP-alk-test (Table 3)

In the solid phase, EDC slightly increased from 116 mg/kg to 124 mg/kg following the low dose application. This anomaly is most likely due to the heterogeneous nature of the soil as discussed above in Section 5.2. EDC reduction took place following both medium and high doses. EDC concentrations decreased from 116 mg/kg to 12.8 mg/kg and 0.06 mg/kg (high dose), an equivalent 89.0% and 99.9% reduction, respectively. In the aqueous phase, EDC reduced from 652,000 µg/L to 497,000 µg/L (low dose), 86,100 µg/L (medium dose) and 243 µg/L (high), an equivalent 23.8%, 86.8% and 99.9% reduction.

For total VOCs, reduction achieved in the solid phase was 88.9% following the medium dose application and 99.9% following high doses. In the aqueous phase, VOC reductions were 25.2% following the low dose, 86.7% following the medium dose application and 99.9% the high dose. The high dose achieved greater than 99% reduction of EDC and total VOCs in both solid and aqueous phases.

TOD measurements showed a $Na_2S_2O_8$ consumption of 3.42 g/kg for the low dose, 9 g/kg for the medium dose and 15.6 g/kg for the high dose over the 10-day period.

Final pH ranged between 11.36 and 12.25 with a control value of 6.6. ORP values were between -159 mV and -211 mV with a control value of 46 mV. TDS values were noted between 18.34 µg/L and 91.74 µg/L with a control value of 10.88 µg/L.

5.2.3 *ASP-heat-test (Table 4)*

Using heat activation, a similar EDC/VOC reduction pattern to that of alkali activation was observed. In the solid phase, EDC was slightly increased from 74 mg/kg to 75 mg/kg following the low dose application, most likely due to the heterogeneous nature of the soil. EDC then decreased from 74 mg/kg to 0.487 mg/kg (medium dose) and 0.053 mg/kg (high dose), an equivalent of 99.3% (medium dose) and 99.9% (high dose) reduction. In the aqueous phase, EDC concentrations decreased from 746,000 µg/L to 568,000 µg/L (low dose), 2,750 µg/L (medium dose) and 200 µg/L (high), an equivalent 23.9%, 99.6% and 99.9% reduction.

Total VOC reductions achieved were 97.2% (medium dose) and 98.7% (high dose) in the solid phase and 24.1% (low dose), 95.2% (medium dose) and 97.9% (high dose) in the aqueous phase. Therefore, both medium and high doses achieved 98% and greater EDC/VOC reduction.

TOD measurements indicated a 1-day $Na_2S_2O_8$ consumption of 4.32 g/kg for the low dose, 18.9 g/kg for the medium dose and 31.8 g/kg for the high dose.

Final pH ranged between 5.37 and 6.18 with a control value of 6.57. ORP values were between 48 mV and 99 mV with a control value of 34 mV, and TDS ranged between 19 µg/L and 55.3 µg/L with a control value of 11.1 µg/L.

5.2.4 *Results and Discussion*

In summary, all three reagents, MFR, ASP-alk and ASP-heat, were effective in treating EDC, the primary site COC, as well as other contaminants detected at the site. In general, using the medium dose, all three reagents were able to achieve 86% and greater EDC/VOC reduction, and using the high dose all three reagents produced approximately 98% EDC/VOC reduction. Among the three reagents, MFR achieved a higher EDC/VOC reduction compared to ASP-alk and ASP-heat at the low dose (60%-73% vs 23%), while ASP-alk produced best results at the high dose leaving the lowest residual VOC concentration in the aqueous phase (667 µg/L) compared to MFR (10,676 µg/L) and ASP-heat (16,900 µg/L).

6.0 CONCLUSIONS AND RECOMMENDATIONS

Results of the bench scale treatability study indicate that MFR, ASP-alk and ASP-heat are all effective towards treating EDC, the primary site COC by achieving greater than 98% EDC reduction in both aqueous and solid phases. The TOD measurements indicated an oxidant demand of $Na_2S_2O_8$ was 4.32 g/kg to 31.8 g/kg for ASP-heat, and 3.42 g/kg to 15.6 g/kg for ASP-alk.

Chemistry vs. Remediation

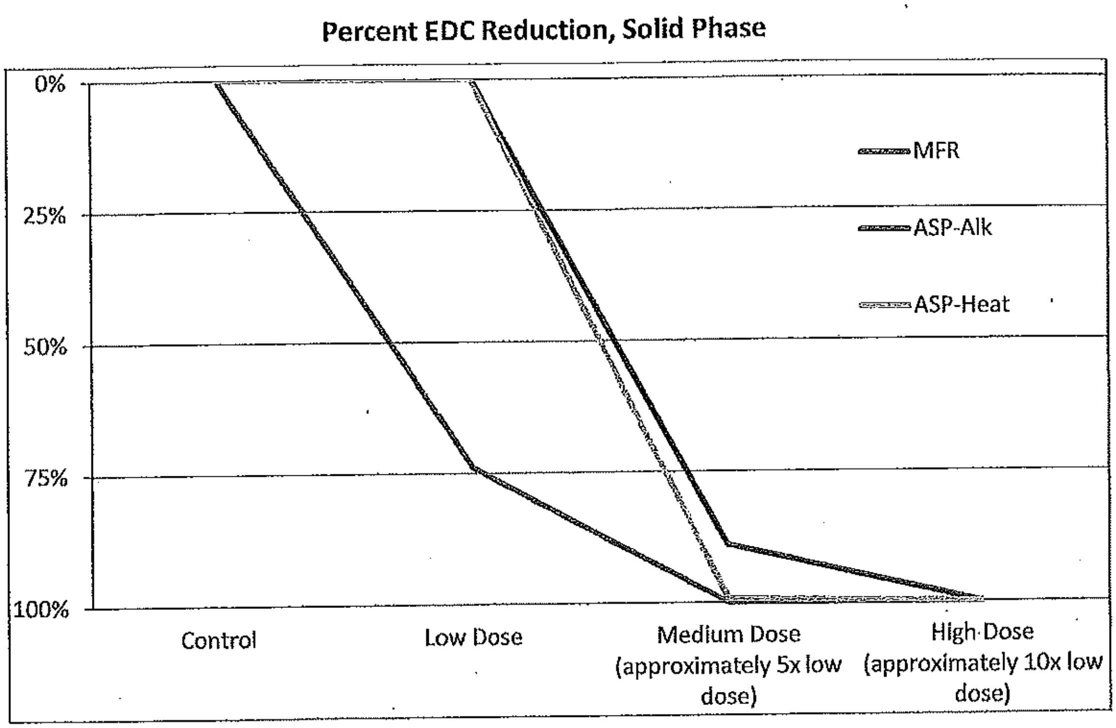
A bench scale treatability study can really only evaluate the oxidation "chemistry" of the various oxidants. The Formosa study evaluated the chemistry of MFR, ASP-alk and ASP-heat on the contaminants present in the site soil and groundwater, primarily EDC. In other words, can each oxidant treat the contaminants present? The answer is yes, each oxidant tested can reduce contaminant concentrations in soil and water under bench conditions.

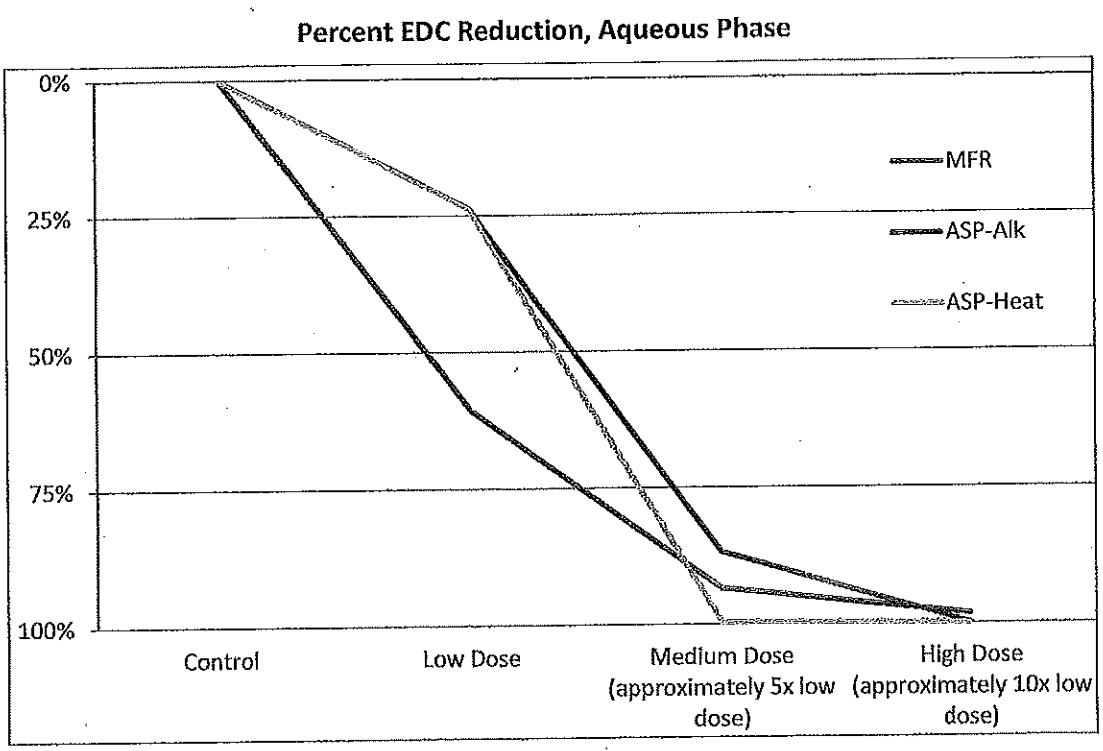
Bench conditions and in-situ conditions are completely different. The bench study started with a soil/water mixture of 2:1 by weight and the soil is comprised of individual particles in a water matrix with mixing. This mixture is an industry standard, but does not simulate in-situ conditions. In-situ conditions have a soil water mixture of approximately 5.8:1, assuming 30% porosity. In addition, the soil particles are compacted and mixing is impossible.

In-situ conditions present a unique set of obstacles to remediation implementation. Remediation is much more complex than bench study chemistry. Remediation requires the combination of injection pressures, volumes and flow rates; reagent type and concentration; and injection location spacing to achieve a uniform (as much as possible) distribution of reagents. Injectable reagent volumes are very site specific depending on grain size, degree of inter-bedded soil types, depth to water and previous penetrations. In general, reagent volumes are limited to 5-10% of a pore volume to prevent surfacing (escape of reagents from the subsurface to the ground). A deep saturated zone comprised of homogeneous gravel will accept a higher volume of reagent, but those conditions are rare. Oxidant concentrations are generally limited to less than 20% due to health and safety concerns regarding handling and surfacing.

Remediation Recommendations

One observation of the bench study data is unique and important. The reduction in concentration in both solid and aqueous phases was very limited in both low-dose persulfate applications, while the MFR low-dose application showed a 61% and 74% VOC reduction for aqueous and solid phase, respectively (See graphs below).


Percent EDC Reduction, Solid Phase
0%
25%
50%
75%
100%
MFR
ASP-Alk
ASP-Heat
Control
Low Dose
Medium Dose (approximately 5x low dose)
High Dose (approximately 10x low dose)


Percent EDC Reduction, Aqueous Phase
0%
25%
50%
75%
100%
MFR
ASP-Alk
ASP-Heat
Control
Low Dose
Medium Dose (approximately 5x low dose)
High Dose (approximately 10x low dose)

Based on the discussion above regarding injectable volumes and concentrations, field applications at the site will mimic low-dose applications. Total contaminant mass reduction comes from a cumulative effect of multiple low-dose applications, as opposed to one large medium-dose application. It does not appear that multiple low-dose applications of activated persulfate will lead to a cumulative mass reduction, since individual low-dose applications are relatively ineffective. However, multiple low-dose applications of MFR should produce a cumulative mass reduction.

Based on the results of the bench study and the inherent application limitations, ISOTEC recommends a field pilot test utilizing MFR as the oxidant.

ISOTEC

TABLES

In-Situ Oxidative Technologies, Inc.

Table 1. Initial Characterization
PBW/Formosa Plastics, Point Comfort, Texas
ISOTEC Project #901132

Sample ID Matrix	P-56 Aqueous		Soil Comp Soil
VOCs	**(ug/l)**		**(mg/kg)**
Vinyl chloride	13,300		ND<0.298
1,1-Dichloroethene (1,1-DCE)	1,780		ND<0.298
trans-1,2-Dichloroethene	4,140		ND<0.298
1,1-Dichloroethane (1,1-DCA)	8,400		ND<0.298
cis-1,2-Dichloroethene	2,650		ND<0.298
Chloroform	81,600		2.1
1,2-Dichloroethane (EDC)	1,280,000	D	44.9
Benzene	2,920		ND<0.298
Trichloroethene	4,590		ND<0.298
1,1,2-Trichloroethane	7,330		0.404
Tetrachloroethene	2,070		ND<0.298
Total VOCs (ug/l)	**1,408,780**		**47.4**
Other Parameters	**(ug/l)**		**(mg/kg)**
Alkalinity	606,000		NA
Nitrate	ND<500		NA
Sulfate as SO4	378,000		NA
Total Organic Carbon (TOC)	8,540		1190
Total Dissolved Solids (TDS)	9,150,000		NA
Ferrous Iron	4,960		NA
Iron	8,710		5,640
Manganese	7,930		136

Note:
ug/l = micrograms per liter. mg/kg = milligrams per kilogram
ND = Compound was analyzed for but not detected at the reporting limit (RL) indicated by the number following "<".
NA = Compound was not analyzed for.
D = The reported value is from a diluted analysis.

Table 2. Treatability Study Results (MFR)
PBW/Formosa Plastics, Point Comfort, Texas
ISOTEC Project #901132

Sample ID	M/Control		M/T-A	M/T-B		M/T-C	
Catalyst Used	none		Cat-4260	Cat-4260		Cat-4260	
Oxidant Used	none		H2O2	H2O2		H2O2	
Oxidant Added (by weight)	0		6.6 g/kg	33.3 g/kg		66 g/kg	
VOCs (ug/l)	Aqueous Phase						
Vinyl chloride	2,760		ND<1000	ND<250		ND<50	
trans-1,2-Dichloroethene	1,520	J	ND<1000	ND<250		ND<50	
1,1-Dichloroethane (1,1-DCA)	2,990		1,120	ND<250		ND<50	
cis-1,2-Dichloroethene	ND<2500		ND<1000	ND<250		ND<50	
Chloroform	37,200		20,500	3,770		2,070	
1,2-Dichloroethane (EDC)	470,000		185,000	30,600		8,190	
Benzene	ND<2500		ND<1000	ND<250		ND<50	
Trichloroethene	1,690	J	ND<1000	ND<250		ND<50	
1,1,2-Trichloroethane	3,730		2,140	744		416	
Total VOCs (ug/l)	**519,890**		**208,760**	**35,114**		**10,676**	
EDC reduction	-		**60.64%**	**93.49%**		**98.26%**	
VOC reduction	-		**59.85%**	**93.25%**		**97.95%**	
VOCs (mg/kg)	Solid Phase						
cis-1,2-Dichloroethene	ND<0.635		ND<0.124	ND<0.00121		ND<0.00125	
Chloroform	2.54		0.779	ND<0.00121		ND<0.00125	
1,2-Dichloroethane (EDC)	64.10		16.70	0.011		0.0063	
1,1,2-Trichloroethane	0.43	J	0.18	0.0005	J	0.0005	J
Total VOCs (mg/kg)	**67.1**		**17.7**	**0.01**		**0.01**	
EDC reduction	-		**73.95%**	**99.98%**		**99.99%**	
VOC reduction	-		**73.66%**	**99.98%**		**99.99%**	
Other Parameters							
ferrous Iron (ug/l)	ND<40.0		ND<40.0	ND<40.0		ND<40.0	
Final pH value (SU)	6.51		6.63	6.90		7.15	
Final ORP value (mV)	185		182	189		203	
Final TDS value (ppm)	5,940		6,286	8,220		11,070	

Note:

ug/l = micrograms per liter, mg/kg = milligrams per kilogram, g/kg = grams per kilogram, mV = milli volts.

ND = Compound was analyzed for but not detected at the reporting limit (RL) indicated by the number following "<".

J = The concentration wasdetected at a value below the RL and above the method detection limit (MDL).

Total oxidant demand is presented as g/kg (grams of oxidant per kilogram of soil).

Table 3. Treatability Study Results (ASP-Alk)
PBW/Formosa Plastics, Point Comfort, Texas
ISOTEC Project #901132

Sample ID	S-A/Control	S-A/A	S-A/B	S-A/C
Catalyst Used	none	NaOH	NaOH	NaOH
Oxidant Used	none	$Na_2S_2O_8$	$Na_2S_2O_8$	$Na_2S_2O_8$
Oxidant Added (by weight)	0	6 g/kg	30 g/kg	60 g/kg
VOCs (ug/l)		**Aqueous Phase**		
Vinyl chloride	ND<5000	3,010 J	3,700	396
trans-1,2-Dichloroethene	ND<5000	ND<5000	260 J	9.24
1,1-Dichloroethane (1,1-DCA)	2,720 J	1,910 J	539	3.42 J
cis-1,2-Dichloroethene	ND<5000	ND<5000	185 J	11.20
Chloroform	41,600	22,300	1,710	ND<5.0
1,2-Dichloroethane (EDC)	652,000	497,000	86,100	243
Benzene	ND<5000	ND<5000	ND<500	1.35 J
Trichloroethene	ND<5000	ND<5000	211 J	2.14 J
1,1,2-Trichloroethane	4,370 J	ND<5000	ND<500	ND<5.0
Tetrachloroethene	ND<5000	ND<5000	183 J	1.51 J
Total VOCs (ug/l)	**700,690**	**524,220**	**92,888**	**667.86**
EDC reduction	-	**23.77%**	**86.79%**	**99.96%**
VOC reduction	-	**25.19%**	**86.74%**	**99.90%**
VOCs (mg/kg)		**Solid Phase**		
Vinyl chloride	ND<0.611	ND<0.624	0.551	ND<0.121
1,1-Dichloroethane	0.416 J	0.469 J	0.076 J	ND<0.121
Chloroform	5.41	4.54	0.201	ND
1,2-Dichloroethane (EDC)	116	124	12.8	0.063 J
1,1,2-Trichloroethane	0.697	ND<0.624	ND<0.125	ND<0.121
Total VOCs (mg/kg)	**122.52**	**129.01**	**13.63**	**0.06**
EDC reduction	-	**increase**	**88.97%**	**99.95%**
VOC reduction	-	**increase**	**88.88%**	**99.95%**
% Oxidant Consumption	-	**57%**	**30%**	**26%**
Total Oxidant Demand (g/kg)	-	**3.42**	**9.00**	**15.60**
Other Parameters				
Final pH value (SU)	6.6	11.36	12.06	12.25
Final ORP value (mV)	46	-159	-199	-211
Final TDS value (ppm)	10,880	18,340	48,500	91,740

Note:
ug/l = micrograms per liter, mg/kg = milligrams per kilogram, g/kg = grams per kilogram, mV = milli volts.
ND = Compound was analyzed for but not detected at the reporting limit (RL) indicated by the number following "<"
J = The concentration wasdetected at a value below the RL and above the method detection limit (MDL).
Total oxidant demand is presented as g/kg (grams of oxidant per kilogram of soil).

Table 4. Treatability Study Results (ASP-Heat)
PBW/Formosa Plastics, Point Comfort, Texas
ISOTEC Project #901132

Sample ID Catalyst Used Oxidant Used Oxidant Added (by weight)	S-H/Control Heat (60°C) none 0		S-H/A Heat (60°C) $Na_2S_2O_8$ 6 g/kg		S-H/B Heat (60°C) $Na_2S_2O_8$ 30 g/kg		S-H/C Heat (60°C) $Na_2S_2O_8$ 60 g/kg	
	Aqueous Phase							
VOCs (ug/l)								
Chloromethane	ND<5000		ND<5000		1,150		571	
Methylene chloride	ND<10000		ND<10000		9,420		4,490	
1,1-Dichloroethane (1,1-DCA)	3,280	J	2,800	J	211		64.80	J
Chloroform	50,900		38,100		15,400		8,210	
1,1,1-Trichloroethane (1,1,1-TCA)	ND<5000		ND<5000		143		107	
Carbon tetrachloride	ND<5000		ND<5000		133		109	
1,2-Dichloroethane (EDC)	746,000		568,000		2,750		200	
Trichloroethene (TCE)	1,680	J	ND<5000		ND<100		ND<100	
Bromodichloromethane	ND<5000		ND<5000		168		89.10	J
1,1,2-Trichloroethane (1,1,2-TCA)	4,860	J	3,340	J	8,310		2,650	
Tetrachloroethene (PCE)	ND<5000		ND<5000		28.1	J	ND<100	
1,1,2,2-Tetrachloroethane	ND<5000		ND<5000		659		410	
Total VOCs (ug/l)	**806,720**		**612,240**		**38,372**		**16,901**	
EDC reduction	-		**23.86%**		**99.63%**		**99.97%**	
VOC reduction	-		**24.11%**		**95.24%**		**97.90%**	
	Solid Phase							
VOCs (mg/kg)								
Methylene chloride	ND<1.22		ND<1.22		0.549		0.372	
Chloroform	2.75		2.90		0.553		0.409	
1,2-Dichloroethane (EDC)	74.00		75.00		0.487		0.053	J
1,1,2-Trichloroethane	0.491	J	0.503	J	0.585		0.176	
Total VOCs (mg/kg)	**77.24**		**78.40**		**2.17**		**1.01**	
EDC reduction	-		increase		**99.34%**		**99.93%**	
VOC reduction	-		increase		**97.19%**		**98.69%**	
% Oxidant Consumption	-		72%		63%		53%	
Total Oxidant Demand (g/kg)	-		4.32		18.90		31.80	
Other Parameters								
Final pH value (SU)	6.57		6.18		6.02		5.37	
Final ORP value (mV)	34		48		57		99	
Final TDS value (ppm)	11,170		19,040		36,150		55,300	

Note:
ug/l = micrograms per liter, mg/kg = milligrams per kilogram, g/kg = grams per kilogram, mV = milli volts.
ND = Compound was analyzed for but not detected at the reporting limit (RL) indicated by the number following "<".
J = The concentration wasdetected at a value below the RL and above the method detection limit (MDL).
Total oxidant demand is presented as g/kg (grams of oxidant per kilogram of soil).